

"CROSS-LINKING PROCESS OF CARBOXYLATED  
POLYSACCHARIDES"

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5 The present invention refers to a cross-linking process of carboxylated polysaccharides.

10 The process of the invention provides a high degree of reproducibility of the obtained products, in terms of cross-linking degree, homogeneity of the distribution of the cross-linking chains, and chemico-physical characteristics of the products and the technological characteristics of the articles obtained therefrom.

The reproducibility is particularly important for the applications in the medical, pharmaceutical and dermo-cosmetic fields.

15 The invention further refers to the products obtainable by said process and their applications in the medical, pharmaceutical and dermo-cosmetic field.

Background of the invention

20 The use of macromolecules in the medical/pharmaceutical field and, more recently, in the dermatological-cosmetic field, is well established. Macromolecules are used in the preparation of pharmaceutical formulations as thickening agents, lubricants, gastro-resistant film coating agents, particularly in the preparation of capsules, gel, colloids and of different devices (e.g. contact lenses, gauzes, etc.). Macromolecules are also used in the preparation of controlled-release formulations of active ingredients.

Reviews of their characteristics and pharmaceutical uses are reported in

- 25 1) C. Hansch et Al. Editors - "Comprehensive Medicinal Chemistry" - Pergamon Press, Oxford, 1990 - Vol. 1-6;
- 2) A. Wade and P.J. Wellers Editors - "Handbook of Pharmaceutical Excipients" - Ed. 1994 - The Pharmaceutical Press.

Said macromolecules belong to different chemical families and may be either synthetic, or natural or semi-synthetic.

Examples of synthetic macromolecules include polyvinylpyrrolidone, polyoxyethylenealkyl ethers, polyvinyl alcohols, polymethacrylates. Examples  
5 of natural macromolecules include native hyaluronic acid (HY) and cellulose.

Examples of semi-synthetic macromolecules include carboxyalkylcelluloses, widely used in the food and personal care industries. These macromolecules are characterized by a linear or poorly branched structure.

10 A very important modification for increasing the chemical, enzymatic and mechanical strength is provided by cross-linking, which may be carried out both on synthetic and natural (more or less already modified) polymers.

Examples of cross-linked polymers include polymers used for the gastro-protection of tablets or capsules (polymethacrylates), as well as polymers used  
15 as emulsifiers, suspending agents, tablet hardeners (Carbopol), cross-linked hyaluronic acids, hereinafter discussed.

For the considered applications, and particularly for the preparation of invasive medical devices which have to be administered parenterally, said polymers must meet a number of requirements, of technical and regulatory  
20 kind.

The technical requirements include:

- 1) high biocompatibility;
- 2) resistance to enzymatic systems, both tissular or plasmatic (for injectable compositions) and gastrointestinal (for oral compositions).

25 In some cases a gradual degradation, for instance for the controlled release of a medicament, may be desirable.

This resistance is particularly important when the macromolecule is present in compositions/articles that must last for a long time, e.g. substitutes

of the synovial fluid, films, sponges or gels as tissular antiadhesives in different kinds of surgery; in tissular engineering (artificial organs); artificial skins, in the treatment of burns and generally in aesthetic surgery;

- 3) moldability into different shapes (gels, films, sponges, etc.);
- 5 4) possibility to be sterilized chemically or physically without changing the product structure.

10 According to the regulatory requisites, the composition of the different production batches must be kept constant within very narrow limits; this implies that the production methods are standardized and that the base components have a very low intrinsic variability.

A possible cause of dishomogeneity for macromolecules derives from the dispersion of molecular weights. Said dishomogeneity becomes even higher as a consequence of cross-linking. This may be a serious drawback depending on the field of use and the applicative purposes of the final product.

15 EP-A-566118 (Kimberly-Clark) discloses cross-linked polysaccharides to be used as super-absorbents for diapers and similar articles.

The process described therein is based on the cross-linking of cellulose by formation of intermolecular amides, esters or ethers between polyamines, polyols or mixtures thereof and the carboxy group of polysaccharides.

20 The reaction is carried out by heating at about 80°C the mixture of the polysaccharide with the polyol and/or polyamine. This process is certainly economic and suitable for large scale production where the reproducibility requirements are less stringent.

US 5465055 discloses cross-linked polysaccharides (hyaluronic acid and 25 alginic acid) obtained by esterification of COOH of the polysaccharide and OH groups of other molecules, without insertion of cross-linking arms.

WO 91/9119 discloses microcapsules for islets of Langerhans as biohybrid organs, consisting of alginic acid cross-linked with barium ions.

EP 190215 discloses the cross-linking of different polymers (carboxylated starches, dextran, celluloses) with di- or poly-functional epoxides.

The following cross-linking agents for hyaluronic acids have been proposed:

- 5 polyfunctional epoxides are disclosed in US 4716224, 4772419, 4716154;  
polyalcohols are disclosed in US 4957744;  
divinylsulfone is disclosed in US 4605691, 4636524;  
aldehydes are disclosed in US 4713448 and 4582865;  
carboxamides are disclosed in US 5356833;
- 10 polycarboxylic acids are disclosed in EP-A-718312.

#### Disclosure of the invention

- The invention refers to a process for the preparation of cross-linked polysaccharides containing carboxy groups, allowing complete control of cross-linking degree as well as high reproducibility in terms of constant
- 15 characteristics of the final product.

The process of the invention comprises:

- a) activation of the carboxy groups of the polysaccharide by reaction with suitable carboxy activating agents in anhydrous aprotic solvent;
- b) reaction of the carboxy activated polysaccharide with a polyamine.

- 20 The obtained cross-linked polysaccharide, if desired, may be subjected to sulphation or hemisuccinylation of the free hydroxy groups.

The products obtainable by the process of the invention may also be complexed with metal ions such as zinc, copper or iron ions.

- The carboxy-containing polysaccharide which may be used according to
- 25 the invention may be of natural, synthetic or semi-synthetic origin. Examples of said polysaccharides include Hyaluronic acids (obtained from tissues or bacteria), carboxymethyldextran, carboxymethylcellulose, carboxymethylstarch, alginic acids, cellulosic acid, N-carboxy-methyl or butyl glucans or

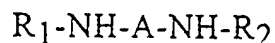
chitosans; heparins with different molecular weights, optionally desulphated and succinylated, dermatan sulphates, Chondroitin sulphates, heparan sulphates, polyacrylic acids.

Hyaluronic acids, carboxymethylcellulose, heparins, alginic acids and polyacrylic acids are particularly preferred.

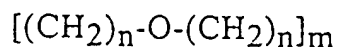
Said cross-linked polymers, obtained by different methods, are known and have been proposed for several uses (see, for instance, EP 566118, WO91/9119, US 5465055, EP 190215, EP 718312, US 4716224 discussed above).

The carboxy activating agents are usually those used in the peptide chemistry: examples of suitable agents include carbonyldiimidazole, carbonyltriazole, chloromethylpyridylum iodide (CMP-I), hydroxybenzotriazole, p-nitrophenol p-nitrophenyltrifluoroacetate, N-hydroxysuccinimide and the like. The use of chloromethylpyridylum iodide is particularly preferred.

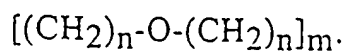
The polyamines have preferably the following general formula:



wherein  $R_1$  and  $R_2$ , which are the same or different, are hydrogen,  $C_1$ - $C_6$  alkyl, phenyl or benzyl groups, A is a  $C_2$ - $C_{10}$  alkylene chain, preferably a  $C_2$ - $C_6$  alkylene chain, optionally substituted by hydroxy, carboxy, halogen, alkoxy, amino groups; a polyoxyalkylene chain of formula



wherein n is 2 or 3 and m is an integer from 2 to 10; a  $C_5$ - $C_7$  cycloalkyl group; an aryl or hetaryl group, preferably 1,3 or 1,4-disubstituted benzene. A is preferably  $C_2$ - $C_6$  linear alkylene or a chain of formula



The cross-linking reaction is preferably carried out in a solvent selected from tetrahydrofuran, dimethylformamide or dimethyl sulfoxide, and the

polysaccharide is preferably salified with a lipophilic cation, for example tetralkylammonium or other lipophilic organic bases.

The transformation of inorganic salts such as sodium salts, into suitable organic lipophilic salts may be carried out by known ion-exchange methods in homogeneous phase or by precipitation of the acidic component, followed by recovering of the latter and salification with the desired organic base.

The activation reaction of the carboxy groups is carried out in homogeneous phase and in anhydrous polar aprotic solvent.

The polyamine diluted in the same anhydrous solvent, is added to the solution of the activated ester, keeping the temperature from 0°C to 30°C. The cross-linking reaction times range from 1 to 12 hours, also depending on the optional presence of suitable basic substances (e.g. triethylamine).

Generally, the final product is recovered by precipitation of the organic salt adding a different solvent to the reaction solvent or by evaporation of the latter, followed by centrifugation, washing with distilled water, repeated dispersions in the solutions of the desired alkali (for instance sodium, potassium), subsequent washing with water and final drying of the alkaline salt under vacuum or by lyophilization.

The cross-linking degree (C.L.D) may range within wide limits and may be adjusted by changing the amount of the carboxy activating agents, since the activation and the cross-linking reaction are substantially quantitative.

The cross-linked polysaccharides obtained according to the invention may be subjected to sulphation reaction of the hydroxy groups possibly present, usually by reaction with the pyridine-sulfur trioxide complex in dimethylformamide.

The reaction is carried out in heterogeneous phase at a temperature of 0-10°C for times ranging from about 0,5 to about 6 hours.

The sulphation degree obtained is comprised within wide limits with

respect to the total of the hydroxy groups and it may be adjusted by changing the temperature and reaction times. Generally, the sulphation degree (defined as equivalents of sulphate groups/g) may range from  $1 \times 10^{-6}$  to  $6 \times 10^{-6}$ , preferably it is of  $2 \times 10^{-6}$  eq/g for a cross-linking degree of 0.5.

5 The cross-linked polymers obtained according to the invention, optionally sulphated, are able to complex metal ions such as zinc, copper or iron ions.

Said complexes may be obtained by dissolving or dispersing until complete swelling the product in water and adding under stirring, preferably at room temperature, a concentrated solution of an organic or inorganic metal salt, e.g.  $\text{CuCl}_2$ ,  $\text{ZnCl}_2$ ,  $\text{Fe}_2(\text{SO}_4)$ ; after stirring for 12-24 hours, the complex is recovered by centrifugation or by precipitation following the addition of a different solvent (for example ethanol or acetone) or evaporation under vacuum; the recovered crude product is thoroughly washed with distilled water so as to remove the excess ions. The complexes are then lyophilized. The content of metal ions varies depending on the used operative conditions, particularly the polymer to ion molar ratios; concentration and pH of the solutions; reaction times and particularly cross-linking degree.

The process of the invention, by suitably adjusting the cross-linking and/or sulphation degree, allows the preparation of cross-linked carboxylated polysaccharides in a wide range of shapes, characterized by different properties such as viscoelasticity, hydration degree, complexing ability towards metal ions, ability to form hydrogels, moldability in films or sponges, mechanical strength of the final materials.

This allows their use in many medical fields, in the human and veterinary field, and in dermo-cosmetology.

The following examples further illustrate the invention.

#### EXAMPLE 1:

Carboxymethylcellulose gel 100% cross-linked with 1,3-diaminopropane.

1,2 x 10<sup>-3</sup> moles, with reference to the disaccharide unit of carboxymethyl cellulare TBA salt, were dissolved in 30 ml of DMF under N<sub>2</sub> and with stirring. 0.32 g of chloromethylpyridylum iodide (1.2 x 10<sup>-3</sup> moles) dissolved in 2 ml of DMF were added dropwise to the solution kept at a temperature of 5 0° C with ice.

The molar ratio was 1 to 1 as carboxymethyl cellulose has one functional carboxylic group per disaccharide unit. After 20 minutes the solution was added with 2 ml of cross-linking 1,3-diaminopropane (0.006 moles), and immediately after also with 0.5 ml of triethylamine. A solid, jelly-like product 10 formed which was washed with DMF, then placed in H<sub>2</sub>O to completely swell.

Alternating washings with EtOH and H<sub>2</sub>O were then carried out. After the last washing with EtOH, the product was freeze-dried.

- I.R. (film; cm<sup>-1</sup>): 1650(-CO-NH-); no bending -COO<sup>-</sup> at 1.400 about.
- SD (Swelling Degree, in water and r.t., after 15'; gravimetric determination; 15 calculated according to:  $SD = \frac{W_s - W_d}{W_d} \cdot 100$ , where:

$W_s$  = weight of hydrated gel;  $W_d$  = weight of dry gel): 7.000

- SEM (Scanning Electron Microscopy): the structure looks compact, with 15-35μ pers.
- 20 - The product surface, by rabbit PRP (Platelet Rich Plasma) exposure, shows a very reduced presence of platelets or aggregates in comparison with equivalent product obtained by low density polypropylene (EC reference standard).

#### EXAMPLE 2:

25 Carboxymethyl cellulose gel 50% cross-linked with 1,3-diaminopropane.

1,2 x 10<sup>-3</sup> moles, referred to the disaccharide unit of carboxymethyl cellulose, were dissolved in 30 ml of DMF under N<sub>2</sub> and with stirring. 0.24 g of chloromethylpyridylum iodide (1.2 x 10<sup>-3</sup> moles) dissolved in 2 ml of DMF were added dropwise to the solution kept at a temperature of 0° C with ice. The

molar ratio was 2/1

After 20 minutes the solution was added with 2 ml of cross-linking 1,3-diaminopropane ( $3 \times 10^{-3}$  moles), and immediately after also with 0.5 ml of triethylamine. A solid, jelly-like product formed which was washed with DMF, then placed in  $H_2O$  to completely swell.

Alternating washings with EtOH and  $H_2O$  were then carried out. After the last washing with EtOH the product was freeze-dried.

- I.R. (film;  $cm^{-1}$ ): 1650( $\underline{CO}$ -NH-); no bending  $\underline{COO}^-$  at 1.400 about.

- SD: 8.000

- SEM: presence of 13-25  $\mu$  pers.

- Platelet adhesion: as reported in Example 1.

### EXAMPLE 3:

Alginic acid gel 50% (100% with reference to disaccharide units) cross-linked with 1,3-diaminopropane.

The TBA salt of alginic has been prepared from the sodium salt by ionic exchange on strong cationic resin (Dovex) in  $H^+$  form (i.e. acidic form), followed by neutralization with tetrabutylammonium hydroxide (TBA-OH) and final liophylisation.

$1,2 \times 10^{-3}$  moles, referred to the monosaccharide unit, were dissolved in 30 ml of DMF under  $N_2$  and under stirring. 0.36 g of chloromethylpyridylum iodide ( $1,2 \times 10^{-3}$  moles) dissolved in 2 ml of DMF were added dropwise to the solution kept at a temperature of  $0^\circ C$  with ice. The molar ratio was 1/1.

After 20 minutes the solution was added with  $6 \times 10^{-3}$  moles of cross-linking 1,3-diaminopropane (0.024 moles), and immediately after also with 0.5 ml of triethylamine. A solid, jelly-like product formed which was washed with DMF, then placed in  $H_2O$  to completely swell.

Alternating washings with EtOH and  $H_2O$  were then carried out. After the last washing with EtOH the product was freeze-dried.

- IR (film;  $\text{cm}^{-1}$ ): 1635 (broad) ( $-\underline{\text{CO}}-\text{NH}-$ ): 1.400, about ( $-\underline{\text{COO}}-$ ).
- SD: 5.000
- SEM: the structure looks compact and without pores.

#### EXAMPLE 4:

- 5 Preparation of hyaluronic acid cross-linked with C.L.D. = 0.05 (5% of available carboxy groups). Cross-linking agent: 1,3-propanediamine.

Hyaluronic acid sodium salt ( $1 \times 10^{-3}$  mol., with reference to the disaccharidic unit) were transformed in TBA salt, according to one of the following methods:

- 10 a) 1% aqueous solution of sodium hyaluronate is transformed in  $\text{H}^+$  form by  $\text{H}^+$  cationic strong resin (Amberlite IR 120); the final solution is treated by a 0,5% solution of TBA-OH to about  $\text{pH}=9$ .
- b) 1% aqueous solution of sodium hyaluronate is transformed in TBA salt solution by treating with a cationic weak resin in  $\text{TBA}^+$  form.
- 15 (Amberlite IRC 50)

In both cases, the final solutions are lyophilised. The TBA salt is then dissolved in 15 ml of anhydrous DMF, under  $\text{N}_2$ , and – at  $0^\circ\text{C}$ - 0,02 g of chloromethylpyridylium Iodide (CMPJ) in 2 ml of anhydrous DMF, are added dropwise to the stored solution of TBA salt.

- 20 The reaction mixture was then added with 0.1 ml of triethylamine and, then, dropwise, with a solution of 1,3-diaminopropane ( $d= 0.88$ , in large excess, so as to make cross-linking of the activated carboxy groups easier) in 2 ml of anhydrous DMF. When the addition was over, the reaction mixture was stirred for at least 30' and the solvent was then removed under reduced
- 25 pressure, the residue was then taken up with DMF, which was subsequently removed by distillation; the residue was then treated with ethanol, ethanol-water and finally with water.

The product was then lyophilised and the residue subjected to analysis.

IR (film;  $\text{cm}^{-1}$ ): 1630 ( $-\underline{\text{CO}}-\text{NH}$ ); 1740 ( $-\underline{\text{COOH}}$ , polysaccharide); 3200 ( $-\text{NH}-$ ).

SD (Swelling Degree, in water and r.t., after 15'; gravimetric

5 determination; calculated according to:  $\text{SD} = \frac{W_s - W_d}{W_d} \cdot 100$ , where:

$W_s$  = weight of hydrated gel;  $W_d$  = weight of dry gel): 31.000

Cross-linking degree: 0.05 (5% of initially available carboxy groups).

#### EXAMPLE 5:

10 Preparation of hyaluronic acid cross-linked with C.L.D. = 0.05 (5% of the available carboxy groups). Cross-linking agent: 1,6-diaminohexane.

Activator: chloromethylpyridylum iodide.

According to the procedure and conditions reported in Example 4, using the same HY and the same activator, but 1,6-diaminohexane instead of 1,3-diaminopropane, the cross-linked derivative was obtained.

15 IR (film;  $\text{cm}^{-1}$ ): 1630 ( $-\underline{\text{CO}}-\text{NH}$ ); 1740 ( $-\underline{\text{COOH}}$  polysaccharide); 3200 ( $-\text{NH}-$ ).

#### EXAMPLE 6:

20 Preparation of cross-linked hyaluronic acid, with C.L.D. = 0.05 (5% of the available carboxy groups). Cross-linking agent: 0.0'-bis-(2-aminopropyl)PEG500. Activator: chloromethylpyridylum iodide

According to the procedure and conditions reported in Example 4 and using the same activator, but 0.0'-bis-(2-aminopropyl)PEG500 instead of 1,3-diaminopropane, the cross-linked derivative was obtained.

25 IR (film;  $\text{cm}^{-1}$ ): 1630 ( $-\underline{\text{CO}}-\text{NH}$ ); 1740 ( $-\underline{\text{COOH}}$  polysaccharide); 3200 ( $-\text{NH}-$ ).

SD: 31.000

**EXAMPLE 7:**

Preparation of cross-linked hyaluronic acids, with C.L.D.= 0.3 (30% of the available carboxy groups). Cross-linking agent: 1,3-propanediamine. Activator: chloromethylpyridylum iodide.

5        0.6 g of hyaluronic acid tributylammonium salt ( $1 \times 10^{-3}$  mol., with reference to the disaccharide unit) were dissolved under stirring in 30 ml of DMF under nitrogen. 0.08 g of chloromethylpyridylum iodide ( $3.5 \times 10^{-4}$  mol) dissolved in 2 ml of DMF were added dropwise to the stirred solution kept at 0°C. The molar ratio was therefore about 3/1.

10        After 20 minutes 2 ml of 1,3-diaminopropane (0.024 mol) were added, followed immediately by 0.5 ml of triethylamine. A solid, gelatinous product was obtained, the product was then swelled with water and washed again with ethanol.

15        The final product, after lyophilisation, shows at the scanning microscope an irregular pattern with smooth zones alternating to spongy zones.

The cross-linking degree was 0.3 (30% of initially available carboxy groups)

IR (film;  $\text{cm}^{-1}$ ): 1740 (-COOH); 1630 (-CO-NH); 1610 (-COO-); 1560 (-CO-NH-)

20    **EXAMPLE 8:**

Preparation of hyaluronic acid cross-linked with C.L.D.= 0.5 (50% of the available carboxy groups). Cross-linking agent: 1,3-propanediamine. Activator: chloromethylpyridylum iodide.

25        0.6 g of hyaluronic acid tributylammonium salt (HY TBA) ( $1 \times 10^{-3}$  mol., with reference to the disaccharide unit) were dissolved under stirring in 30 ml of DMF under nitrogen. 0.15 g of chloromethylpyridylum iodide (CMPJ) ( $6 \times 10^{-6}$  mol) dissolved in 2 ml of DMF were added dropwise to the solution, kept at 0°C. The molar ratio was 2HY.TBA:1 CMPJ. After 20 minutes, 2 ml of

1,3 diaminopropane (0.024 mol.) were added to the solution.

0.5 ml of triethylamine were added thereafter.

A solid, gelly-like product was obtained and thoroughly washed with DMF.

5 After evaporating DMF, the product was swelled in water and washed with ethanol before lyophilization.

The obtained product had a cross-linking degree of 0.5 and showed at the scanning microscope a grainy aspect interspaced by large meshes. At higher magnitudes, the two morphologies appear identical and show round-shaped protrusions a few microns in diameter.

IR (film;  $\text{cm}^{-1}$ ): 1740 ( $-\text{COOH}$ ); 1630 ( $-\text{CO-NH-}$ ); 1610 ( $-\text{COO}^-$ ); 1560 ( $-\text{CO-NH-}$ );

The gels were subjected to swelling in PBS and the max swelling ability was evaluated.

SD= 23.500

NMR = (13 C; ppm): 29.3 and 39.8 ( $-\text{CH}_2-\text{CH}_2-\text{CH}_2-$  propanediamine link); 172.5 ( $-\overset{\text{O}}{\underset{\text{O}}{\text{C}}}-\text{NH}-\text{CH}_2-\text{CH}_2-\text{CH}_2-$ )

The rheological properties evaluated on Bohlin VOR Rheometer, at the temperature of  $23 \pm 0.1^\circ\text{C}$ , show that the dynamic elastic module  $G'$  (100Pa at 10Hz) identical at the two considered concentrations (10 and 20 mg/ml) is always higher than the viscous dynamic module ( $G''$  40 Pa for 20 mg at 10Hz and 20 Pa for 10 mg at 10Hz).


## 25 EXAMPLES 9 - 12

According to the methods disclosed in the previous examples, the cross-linked hyaluronic acid derivatives having the characteristics summarised in the following table 1, were obtained, starting from  $1 \times 10^{-3}$  mol (0.6 g) of hyaluronic

acid tributylammonium salt.

The obtained derivatives had the following properties:

TABLE I

Ex	Cross-linking agent (mol)	Amount (g) of CMPJ (mol)	Cross-linking degree	SD	NMR (13) (ppm)	I.R. (film) (cm <sup>-1</sup> )	Scanning Electron Microscopy (SEM)
9	1,3-propanediamine (0.024)	0,6g (1.210 <sup>-3</sup> )	(100%)	13.200	29.3/39.8 (-CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -link); 172.5 (-C(=O)-NH-CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -) 	1630 (-CO-NH-); 1560 (-CO-NH-);	Homogeneous, undulated morphology.
10	0,0'-1-bis-(-2-aminopropyl) PEG 500 (0.022)	0,15g (6x10 <sup>-4</sup> )	(50%)	9.000			Alternating smooth areas and meshes, circular protrusions a few microns in size.
11	0,0'-bis (2-aminopropyl) - PEG 800 (0.022)	0,15g (6x10 <sup>-4</sup> )	(50%)	6.100			Two morphologically different zones, a first one undulated and a second with hole-like structures.
12	1,6-diaminohexane (0.023)	0,15g (6x10 <sup>-4</sup> )	(50%)	8.000	169.46(-CO-NH- of cross-linking); 74.04/76.80/83.17/80.41(-CH2- of cross-linking arm)	1740 (-COOH); 1630 (-CO-NH-); 1610 (-COO-); 1560 (-CO-NH-);	Smooth surface with protrusions having a few microns in size.

EXAMPLE 13:

Sulphation of 50% cross-linked HY,

The derivative obtained in example 8 was dispersed in 5 ml DMF under strong stirring and nitrogen atmosphere.

- 5 A solution of 1 g of  $\text{SO}_3$ /pyridine in ml of DMF was added at  $0^\circ\text{C}$  and stirred for 3 hours. The reaction was blocked by adding an excess of  $\text{H}_2\text{O}$  (50 ml) and the pH adjusted to 9 with 0.1M NaOH.

The product was thoroughly washed with ethanol and  $\text{H}_2\text{O}$  and then lyophilized.

- 10 The IR spectrum shows, in addition to the bands of the starting product, a peak at  $1260\text{ cm}^{-1}$  and a stronger band at  $1025\text{ cm}^{-1}$ .

- The gel swells in PBS with  $\text{SD} = 33.000$ . Higher resolution  $^{13}\text{C}$  NMR spectrum shows the signals in  $\text{H}_2\text{O}$  at  $37^\circ\text{C}$  reported in table 2. The intensity of the NMR signals at 29.3 and 38.8 ppm ( $-\text{CH}_2-$ ) and the signal at 172.5 ppm  
15 (CONH) confirm a cross-linking degree of about 50%.

- The rheological properties are characterised by dynamic elastic modules  $G'$  (2500Pa with 20 mg and 1000 Pa with 10 mg at 10Hz) which are always higher than the dynamic viscous modules  $G''$  (600Pa with 20 mg and 150 Pa with 10 mg at 10Hz) and much higher than the corresponding values obtained  
20 with non-sulphated HY (13 at 50% - example 5). This compound has a thrombin time (TT) higher ( $61 \pm 5''$ ) than the control ( $14.0''$ ) and the corresponding not cross-linked ( $14.6''$ ).

The compound was also active in the PRP test using stressed rabbit.

TABLE 2

Table:  $^{13}\text{C}$  Chemical shift

C-1	C-2	C-3	C-4	C-5	x-C=O	y-CH <sub>3</sub>	
103.5	57.3	85.4	71.3	78.7	178.0	25.3	ppm
C-1'	C-2'	C-3'	C-4'	C-5'	6-C=O		
105.9	75.2	76.4	82.8	78.6	176.2		ppm
1-CH <sub>2</sub>	2-CH <sub>2</sub>	3-CH <sub>2</sub>	6'-C=O	CROSS- LINKING			
39.8	29.3	39.8	172.5				
							ppm

5 **EXAMPLE 14:**

## Sulphation of Alginic acid GEL

The cross-linked product after treatment with EtOH was freeze-dried to remove completely humidity and subjected to sulphation of the alcohol groups.

100 mg of cross-linked product dispersed in 5 ml of DMF were added with a SO<sub>3</sub>-pyridine solution of (800 mg in 2 ml of DMF). The reaction should be carried out at 0° C, under nitrogen and with constant stirring for 2 hours.

It is mandatory for the product not to adsorb humidity, as it inhibits the reaction.

After 2 hours H<sub>2</sub>O was added pH was adjusted to 9 by a 1M solution of NaOH, thereby freeing pyridine.

The thus sulphated product was purified in EtOH.

The analysis of purified products, shows:

- IR (film; cm<sup>-1</sup>) 1263 (stretching SO)
- Equivalents of SO<sub>3</sub> groups/g gel (by toluidine complexes):

5% cross linked gel:  $6 \times 10^{-5}$

50% cross linked gel:  $2 \times 10^{-5}$

100% cross linked gel:  $3 \times 10^{-5}$

SD

5% cross linked gel:  $19 \times 10^3$

50% cross linked gel:  $9 \times 10^{-3}$

100% cross linked gel:  $7 \times 10^{-3}$

5 EXAMPLE 15:

Using the same methodology, the sulphated derivatives of 50% cross-linked products according to example 10,11 and 12, have been synthesized.

Colorimetric characteristics of the sulphated derivatives are reported in table 3 together with that of the products deriving from examples 8 and 13.

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524
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TABLE 3

CROSSLINKED (50% DEGREE)	POLYMER CROSS-LINKING	$\Delta H_a$ [J/g]	$T_g$ [°C]	$\Delta H_b$ [J/g]	Wt % water
C.L.Hyal - 1,3 (Ex. 8)		276	51	42	12
C.L.HyalS - 1,3 (Ex. 13)		357	64	53	16
C.L.Hyal - 1,6 (Ex. 12)		327	64	58	16
C.L.HyalS - 1,6		465	64	65	20
5 C.L.Hyal - P500.2NH <sub>2</sub> (Ex. 10)		239	45	72	10
6 C.L.HyalS - P500.2NH <sub>2</sub>		384	69	113	16
7 C.L.Hyal - P800.2NH <sub>2</sub> (Ex. 11)		179	73	30	10
8 C.L.HyalS - P800.2NH <sub>2</sub>		206	76	52	10
Hyal ITBA		164	-	130	5

 $\Delta H_a$  [J/g]: water vaporizationenthalpy $T_g$  [°C]:

enthalpy for thermal degradation process

 $\Delta H_b$  [J/g]: glass transition temperateWt % water: % of water content, based on  $\Delta H_a$

EXAMPLE 16:

Suphation of carboxymethylcellulose gel.

Following the procedure and conditions reported in Example 14, the sulphated derivative was obtained.

5 - Equivalents of  $\text{SO}_3$  groups/g:

a- CMC 5% cross linked:  $8 \times 10^{-6}$

b- CMC 50% cross linked:  $7 \times 10^{-6}$

c- CMC 100% cross linked:  $4 \times 10^{-6}$

SD

10 a:  $20 \times 10^{-3}$

b:  $12 \times 10^{-3}$

c:  $9 \times 10^{-3}$